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**A New Method to Evaluate, Optimize, and Forecast
Human and Robot Performance in 21st Century Space Operations**

Revolutionary advances in human and robot cooperation will enable bold, innovative capabilities for scientific reconnaissance and exploration of planetary surfaces, for permanent presence beyond low Earth orbit, and for eventual development of space resources for use on Earth and in space. The ultimate extent of these future capabilities is unbounded, as it depends on yet to be made but anticipated innovations at the intersection of such areas as robotics, human factors, information technology, bio-technology and highly miniaturized (e.g. nano-scale) electronic systems. In order to capitalize on the great opportunities enabled by these revolutionary technologies, it is essential to define and design new human-robot architectural concepts that minimize risk, while optimizing the performance that both humans and robots working together can achieve. This is one of the challenges for the community attending this workshop.

Human and robot skills are synergistic and complementary. Humans provide as yet unmatched capabilities to perceive, think, and act when faced with anomalies and unforeseen circumstances, but there are huge potential risks to human safety involved in getting these benefits. Robots provide complementary skills in being able to work in extremely risky environments, but their ability to perceive, think, and act by themselves is currently not error-free, although these capabilities are continually improving with the emergence of new technologies. There is substantial historical evidence to validate these generally qualitative notions. For example, N. Armstrong's celebrated terminal descent maneuver to the lunar surface could most probably not be done reliably, even now, several decades after the event occurred. In contrast, robots have survived at Venus, Jupiter and other very extreme environments, not likely to be endured by humans in the foreseeable future. There are myriad similar historical anecdotes, both on Earth and in space, that suggest the relative strengths of humans and robots. This evidence is undoubtedly all accurate. However, such evidence must now be augmented with a more rigorous analytical framework that enables systematic, quantitative evaluation of human and robot roles, in order to optimize the design and performance of human-robot system architectures using well-defined performance evaluation metrics.

This talk summarizes a new analytical method to conduct such quantitative evaluations. Ideas from several disciplines, including robotics, human factors, and information and system theory are combined into a unified analytical framework for performance evaluation, optimization and forecasting. The method is generically applicable to all scenarios, including past, current and future missions. The talk discusses how to compare quantitatively the performance of a large variety of human-robot systems, how to optimize the allocation of roles to humans and robots, and how to forecast future performance. The results of 2 representative case studies, one in surface science exploration and the other in space assembly of large telescopes, are used throughout to illustrate the application of the method.